Energy coordination in eco-districts: The multi-disciplinary NEXUS project

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Abstract: Funded by ADEME (French Environment and Energy Management Agency) the NEXUS project aims at identifying innovations in energy storage and management (especially of intermittent renewables) at the level of eco-districts or city blocks. The multi-disciplinary analysis involves technological, sociological, economic, city planning and political dimensions[1].

The research analyses *socio-energy nodes* (SEN) at district or block level. SENs are seen as the place of the coordination among district stakeholders, from real estate, energy and city planning actors to constructors or investors. Deploying appropriate technical systems, SENs are supposed to be more or less replicable from a territory to another.

The project studies the arrangement and deployment conditions of SENs at district level and describes them through a portfolio of contrasted scenarios (including smart grids) in view of a 2040 goal of dividing greenhouse gases by 4. These scenarios will propose visions of districts or blocks able to smoothen energy intermittencies, using assumptions about economic constraints, technological capacities, regulatory context and political decisions at local and national scales.

Besides managerial issues, this project contributes to theoretical development in the disciplines represented by the research team. It deepens the concept of "urban assemblage" (based on Actor-Network Theory) by exploring the technical knowledge and skills activated in innovative urban projects. It broadens the scope of the business model literature by exploring business model innovations brought about by the energy transition. It explores models of energy supply across the district by a techno-economic analysis which tries to characterize technical configurations and economic fundamentals of local sub-urban energy systems with low energy consumption and high shares of renewable and local energy sources. It finally

[1] This communication mobilizes results of the research project « Ecoquartier NEXUS Energie » (Eco-district NEXUS energy), co-funded by ADEME (French Environment and Energy Management Agency), and led by the laboratory PACTE-CNRS (coordination Gilles DEBIZET), the federative research structure INNOVACS, the laboratory EDDEN (UPMF), the INES (CEA) and Grenoble Ecole de Management: http://www.nexus-energy.fr/

explores links between modes of governance and institutional innovations linked to energy efficiency and diversification efforts.

Introduction

Buildings are responsible for 40% of energy consumption and 25% of greenhouse gas emissions in France. Achieving the objectives of "factor 4" (cut greenhouse gas emissions by 75%) by 2040 implies a drastic reduction of energy consumption and a shift towards non-carbon energy sources. The expected decrease of fossil fuels and increase of intermittent renewable energy sources will enlarge the time interval between energy production and consumption. At the same time, the pooling of energy production equipment could become increasingly decentralized, towards buildings in cities and villages. The time interval between production and consumption and its uncertainty are an important problem for electricity grids and power plants (Hadjsaid et al. 1999), especially in countries such as Germany where the instantaneous price of electricity varies increasingly and reduces dramatically the incomes of electricity companies (Feix, 2013).

This problem of electricity grids lead to two main kinds of solutions: on the one hand, increasing electricity production and storage (CRE, 2012), on the other hand, mastering electricity demand (of home-occupants, office or industrial consumers) via economic signals (Bergaentzlé & al., 2014). However, the distinction between electricity operators and consumers is becoming too limited. First, more and more electricity consumers become electricity producers. Second, electricity consumers consume electricity mainly for heat uses (especially in France[2]) and could make a choice among different energy subsidies. However, when moving into a new house, a consumer inherits the electrical connection and the system of heat production. So, electricity demand and production depend on the organization of heat production at the city and building level.

The NEXUS project explores a third way between increasing electricity supply and mastering electricity demand to manage the problem of intermittent renewable energy. We assume that buildings, city blocks and districts could be the scales of energy storage in order to temporize the gaps between energy (including electricity) consumption and production. We assume that energy storage inside cities will mainly depend on the energy systems installed in cities. And decision makers of energy systems define the future energy management inside cities: building developers and owners, energy distributors and urban project leaders build and transform the city according to energy and building regulations defined by public authorities.

Imagining 2050 scenarios for energy storage inside cities requires wide knowledge regarding the coordination of energy systems: future technological capacities, economic constraints, urban dynamics, regulatory contexts, political decisions at local and national scales and future consumption patterns. In order to investigate all these aspects and engage in prospective work, broad knowledge is required, in particular of: building and energy technologies; techno-economic systems around energy solutions;

[2] Nearly 3/4 of the electricity in the residential sector is consumed for heating and warm water in France (ADEME, 2013)

business model dynamics in energy markets; regulation and organization of the energy sector; sociology of organizations; urbanism and a systemic approach of urban territories.

The specificity of the NEXUS project is to rely on multidisciplinary skills with the aim of designing individually consistent scenarios of energy coordination in 2040. These scenarios explain the relationships between stakeholders as well as the rules defined by the public authorities.

The project involves geographers, planners, sociologists, political scientists, economists and engineers. The different fields represented in the research project reflect the multiplicity of actors involved in the eco-districts. Each discipline has a specific way to analyze the question of energy coordination: the weight of explanatory factors differs according to disciplines. That is why we do not privilege deterministic theory as some disciplines would. Follower of the actors-networks theory, Farias considers the city as "*an object, which is relentlessly being assembled (…) as a multiplicity of processes of becoming, affixing sociotechnical networks, hybrid collectives and alternative topologies*" (Farias & Bender, 2010). Based on this concept of urban assemblage, we could consider that energy systems inside cities are being assembled by a multiplicity of actors and devices.

We assume that the smallest scale of an energy system is a group of physical elements built by the same decision maker: a building developer (or owner) or an energy distributor or any intermediary constructor or investor. We name it *socio-energy node* (SEN). Assemblages of SEN compose the energy system(s) of the city. The SEN is the smallest common unit and allows a common language between scientists involved in the NEXUS project. The next figure represents examples of energy flows and (non assembled) SEN: a district heating unit managed by a local utility company and a heat pump led by a building developer. Decision-makers of other SEN (power transformation, combined heat and power, biomass boiler, substation) are not represented.

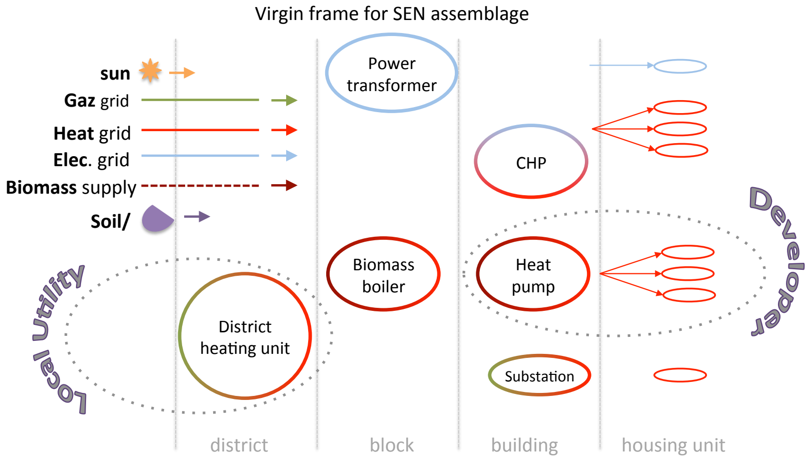

Figure 1: Examples of energy flows and SEN on a district frame

The NEXUS project imbricates interdisciplinary productions and several monodisciplinary analyses as much as possible on the same corpus: several disciplinary analyses of selected European eco-districts; a survey of the main stakeholders of the energy systems in four French eco-districts; knowledge production on frameworks and innovation; and the development of scenarios about energy coordination in 2040 freed from the current regulatory constraints.

This last phase is currently in the works. So, we focus this paper on research design, new knowledge from this interdisciplinary research and further perspectives of research.

I. Research questions

The NEXUS project responds to a social issue that concerns a growing number of energy actors: what are the possible solutions in terms of (intermittent renewable) energy storage and management at the level of eco-districts or cities? We make three assumptions:

- the management of intermittency is (or should be) part of the coordination of energy systems that is concomitant to the transformation of the city.

- this coordination is governed – more or less intentionally – by national and local regulation of energy and construction markets

- the spreading of socio-technical innovations needs a long-term reliability of urban and market regulations[3].

By itself, the NEXUS research does not assume a predominant mechanism between the regulatory system and the coordination modes mobilized in the city. Each discipline involved in the project has a specific point of view on these links. In this paper, we investigate four research questions related to energy intermittency in urban areas:

- How can an innovative scale of energy coordination (to design block or district heating) reveal an existing reference framework interlocking public regulation and expertise cognition?

By using the concept of urban assemblage (Farias & Bender, 2010) for the multiple, partially localized networks, spaces, and practices within cities, scientists can identify current links between actors. Some actors constraint not only a particular actor but many actors acting in the same territory. With a historical point of view, powerful organizations, public regulations, social representations and expertise could be considered as elements of a reference framework (Flichy, 1995) that characterizes both a territory and a period. Identifying the strongest elements of a reference framework by exploring the current projects is a scientific challenge.

- How do organizations transform their business models to manage the energy storage and diversification at the different urban scales?

Many scholars (e.g, Bohnsack & al., 2014; Boons & al., 2013; Charter & al., 2008; Johnson & Suskewicz, 2009; Schaltegger & al., 2012; Tukker & Tischner, 2006; Wells, 2008) have noted that the business model issue deserves more attention in the field of sustainable solutions, in particular because sustainable solutions require not only technological innovation but also business model disruption. The business model determines how a company generates value/ money and comprises 4 elements: value proposition, supply chain, financial model and customer interface. Schaltegger & al. (2012) state that "the business case for sustainability has to be created (and managed) – it does not just happen", and present a framework for business model innovation as a means to create this business case. The NEXUS project focuses on sustainable solutions for energy storage and management in eco-districts.

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[3] Long term economic viability is required for adopting emergent technologies (Madlener, 2007)

- How does the energy diversification within the same building or neighborhood and between different urban scales require innovations in institutional operations and functions as well as in project governance modes?

These questions relate to two sets of related issues related to obstacles to institutional changes. The first, and on a more general level, is Pierson's (2000) notion of path dependency[4], which aims to explain how a decision taken in the past (for example, the development of coal or nuclear energy in a country) will then limit and structure an organization's capacity to change when faced with new challenges (which will later impact its capacity to reach climate – coal – or energy diversification objectives – nuclear). Thus, initial decisions may help or hinder that capacity, depending on the new issue or challenge. Policy Science scholars have explored and explained this by analyzing, for example, the individuals' role within the organizations, institutional structure, decision and governance modes and the role of power...

The second is exemplified by Young, who focused specifically on an issue closely related to ours; an institution's capacity to reach environmental objectives. According to the author, an institution can see its efforts at reaching environmental objectives slowed or even negated by its own internal operations, structure and even identity - which he called institutional fit- no matter its intentions. In pragmatic terms, factors such as habits, institutional culture, financing modes, employees' skills and fields of specialization all play a role. Young puts forward that the institutions' embedded "stickiness" may require changes in operations and identity if environmental objectives are to be reached. We explored these questions by addressing issues linked to energy efficiency and diversification at the sub urban level in NEXUS. What are internal and external obstacles to change? What governance mode was adopted for the projects?

- Why do energy systems implemented in French eco-districts differ from other European ones?

The aim of local energy and climate policy differs across European countries, reflecting national concerns about energy independence, nuclear phase out or development of local renewable resources (Emelianoff & Mor, 2013). These different concerns, the national regulation framework and the diversity of power and skills at the local level result in very different choices as regards the energy systems for the eco-districts (Bulkeley & al., 2011; Fayman & al., 2011; Rohracher & Späth, 2014).

II. The NEXUS project

a. an original research method

The NEXUS project aims at developing scenarios about the socio-energy nodes, with the aim of providing strategic recommendations for public policy. The project partners establish the hypotheses

- that socio-energy nodes are reproducible from one district or city to another
- that socio-energy nodes have different dimensions (urban planning, politics, business model, organization, technology…) that are all more or less dependent on national and regional regulation

[4] Path dependency was first an economic theory. Paul Pierson (2000) applied it to the policy science field.

Therefore, the analysis of socio-energy nodes of one district, complemented by punctual analyses of innovative socio-energy nodes in other districts, allows us to define drivers and impediments of their utilization in other eco-districts until 2020, and then, design possible scenarios for 2040, based on hypotheses about future technologies and regulation. The difference between these two dates lies mainly in the general action framework of the building and renovation sector. In 2020, the framework is assumed to be very similar to the current one, while sets of assumptions about future institutional, political and economic (local or national) regulations will lead to prospective scenarios for 2040.

The project has 4 steps. Step 1 analyzed eco-districts in Europe, taking into account the state of the art in terms of energy supply, from a geographical, political, technological and business model point of view. A first intermediary report (October 2012) proposed an inventory and a typology of eco-districts, according to their governance and energy supply. Step 2 consisted of semi-directive interviews with actors involved in the construction of selected eco-districts – it aimed at understanding how SEN were constructed. A second intermediary report (September 2013) focused on both social interactions and technical configurations relative to energy supply at block and district levels. Step 3 was dedicated to the development of 4 sharply contrasted future scenarios. The scenarios were developed by the research partners, and complemented by the opinion of a panel of experts (real estate, energy, urban planning…).

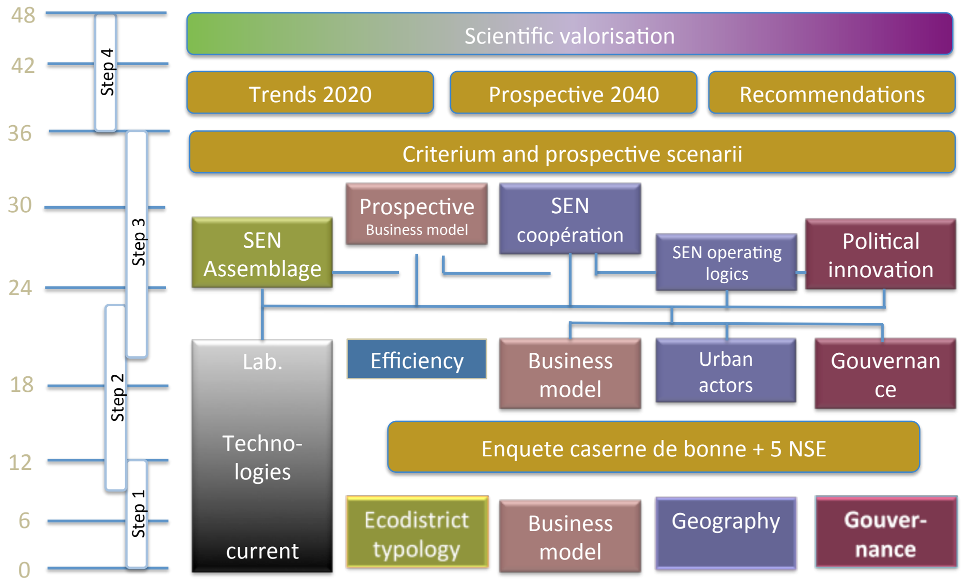

Figure 2: Steps of the NEXUS research project

The method chosen for the panel of experts was the FAcT-Mirror method, a method mirroring interactions and feelings between actors involved in energy management at district, block and building level (June 2014). Step 4 will consist in making recommendations for decision-makers, in particular regulators.

The FAcT-Mirror method
The FAcT-Mirror method was originally developed to build collaborative inter-professional teams (Le Cardinal et al., 2001). In FAcT-Mirror, we assume that the forms of cooperation among actors depend on fears, attractions and temptations felt on both sides of a relationship. The method allows in two or three days to generate an action plan co-built and shared by all the protagonists of a project. In the NEXUS project, FAcT-Mirror has been adapted to provide information about consensus and disagreement between the actors involved: central government, local communities, companies supplying energetic solutions, and private individuals (organized in condominiums, cooperatives, or other). This information is given via the revealed feelings (fears, attractions and temptations) and is matching with pre-selected variables identified by the research partners as key issues. A workshop is organized to meet representative actors and reveal their feelings about their cooperation in an infra-urban energetic system, with a focus on the intermittency management. The pre-selected variables (and potential additional variables emerging from the results) are characterized in terms of consensus and disagreement among actors. This workshop is the center block of the FAcT-Mirror method. This two-day long FAcT-Mirror workshop has 7 stages: 1) reformulation of common objectives of all actors 2) listing of actors and their main interactions 3) inventory of fear, attraction and temptation (PAT) of an actor toward another, given the common objective 4) anonymous rating of all mentioned fears, attractions and temptations, identification of the most and the least consensual feelings 5) grouping of fears, attractions and temptations, and connection with predefined (and maybe new) variables, identification of the most important variables and blocking points 6) development of recommendations aiming at reducing fears, and preventing temptations 7) individual rating of recommendations highlighting consensus and disagreement among different categories of actors The recommendations formulated by the participants to decrease fears and increase attractions are not integrated as usual in an effective action plan, but analyzed to find potential synergies or incompatibilities between variables. The workshop's result will be used to fine-tune the variables and scenarios developed by the research partners, and to elaborate policy recommendations.

b. Data

i. Step 1: Analyses based on a literature review

12 eco-districts in Europe were selected among sixty pre-identified ones. Six are located in France: De Bonne in Grenoble, Confluence in Lyon, St-Jean des Jardins in Chalon sur Saône, Ginko in Bordeaux, Grand Cœur in Nancy, Plateau de Haye in Nancy. Six are located in other European countries: Vauban in Freiburg (Germany), Hammarby Sjöstad in Stockholm (Sweden), Royal Seaport in Stockholm (Sweden),

Kronsberg in Hannover (Germany), Bedzed in Sutton (UK), Poblenou in Barcelona (Spain).

For each eco-district, we collected data on the context, the main objectives, the main stakeholders, the energy objectives, the implemented energy systems and their governance.

ii. Step 2: Empirical case studies on four French eco-districts

4 French eco-districts were selected for empirical analysis: 2 in the Grenoble area near Lyon – De Bonne in Grenoble and Bastille in Fontaine, and 2 in the Paris area - Sainte Geneviève in Nanterre and IssyGrid® in Issy-les-Moulineaux.

20 interviews were conducted at the **Caserne de Bonne** (Grenoble): local authority representatives, town and energy planners, urban project managers, architects and energy consultants, local energy operators and, for four building projects, developers, architects, energy consultants and representatives of inhabitants. Three buildings were new constructions: a residential building, a social housing block and an office building with a positive energy performance[5]. The fourth is a refurbishment of an old military office into a residential and commercial building.

De Bonne eco-district is located on a former military site close to the city center. This urban project includes 800 residential units, a commercial and leisure center, school and several residential services for elders, students and tourists. It was awarded by the European Concerto program in 2005 and by the French Government in 2009 for its energy performance (designed ten years prior to the current building energy rule) and the variety of energy resources: PV and solar thermal panel, heat and power units, urban heat...

Four to five interviews were conducted at each of the three other eco-districts.

In Nanterre and Fontaine, we interviewed municipality representatives and directors, energy consultants and/or energy contractor project manager and building developer.

- Bastille is an urban regeneration project located at Fontaine, a suburb of the Grenoble area. Several new social housing buildings, a refurbishment of a condominium, new streets and a heat grid alimented by a wood heat plant compose this project.

- Sainte-Geneviève is a new development on a former industrial site located at Nanterre, a suburb of Paris. 600 residential units composed of residential real estate and social housing are connected to a heat grid alimented by heat from wastewater and geothermic probes.

The fourth surveyed field was **IssyGrid®**, a smart grid experimentation led by several companies located in a district of Issy-le-Moulineaux, a suburb of Paris. The companies collaborate together to experiment with information and electricity flows among their office buildings. The experimentation includes a car battery storage connected to the electric grid of an office building, PV panels, and the mitigation of consumption peaks by associating office and residential buildings. We interviewed the main stakeholders of this voluntary collaborative smart grid.

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[5] A positive energy building produces annually more energy than it consumes.

Most interviews were conducted by two different scientists (e.g. a sociologist and a geographer, or a management scientist and an urban planner). The interviews followed a common and interdisciplinary grid of questions. After transcription of the audio record, the interviews were coded with computer-assisted qualitative data analysis software according to a common framework.

iii. Step 3: Development of future energy coordination scenarios

After the analyses based on a literature review and the empirical case studies, the following independent variables defining future scenarios were identified:

- Logic of the actors involved in "socio-energy nodes"
- Public policies and regulations
- Scale of energy systems
- Autonomy, self-consumption and autarchy
- Inequality and precarity
- Sociotechnical and systemic resilience

The prior analysis of eco-districts fed the elaboration of these variables; this analysis especially highlights the interactions between variables.

Four scenarios for 2040 are being designed. They differ according to the main decision-makers regarding energy choices and investments:

- Scenario "private companies": Large companies are predominant in energy and building markets. These markets are mainly (and weakly) regulated at the European or global level. Local authorities have a weak regulatory power.
- Scenario "cooperation among local actors": Local public and private actors develop cooperative solutions for energy access and energy management. They can easily exchange energy.
- Scenario "local authorities": Local authorities make detailed prescriptions and impose procedures for energy distribution and also building construction and refurbishment. They can actually mandate energy resources and the scale of energy production to developers and owners.
- Scenario "central government": The central government (France, European Union) makes detailed prescriptions and imposes uniform procedures for energy distribution and also building construction and refurbishment.

c. Results according to research questions

- Why do energy systems implemented in the French eco-districts differ from other European ones?

The review of the experience regarding eco-districts reveals great differences between the European projects. At the European level, eco-districts differ in terms of emission reduction targets, relative importance of energy issues, focus on energy efficiency versus renewable energy sources, reliance on innovative energy technologies, etc. Differences between countries regarding the aim of national energy and climate policies explain local choices at the urban level. Decentralization of the administrative structure and the traditional role of local authorities in the energy system also result in specific socio-technical configurations as regards eco-district supply energy systems.

In France, this comparison shows that most projects focused on highly energy efficient new buildings and/or ambitious thermal renovation plans, or efficient district heating systems using renewable energy sources or combined heat and power. On the other hand, the eco-districts in French cities are less interested in local electricity supply or demand side management (except very recent experiences with smart grids) while these approaches are very common in other European countries.

The reason for that is twofold. First, local authorities have traditionally, in France, little or no control over energy supply at the local level except as regards district heating systems. Second, the electricity mix in France is very low carbon intensive because of the contribution of nuclear and hydro energy to electricity production. As a consequence, the reduction of energy dependency, the control of high electricity prices, or the reduction of greenhouse gas (GHG) emissions in the electricity mix are less important in the political agenda of French cities compared to other European ones. In France, electricity is not a priority in the energy supply of eco-districts, the objective clearly is the reduction of heat demand or the substitution of fossil fuel heating (combined heat and power, renewable energy sources).

Moreover, the survey shows that there was no concern about energy intermittency in the three eco-districts led by municipalities; intermittency concerns mainly actors of smart grids.

Some recent experiments expand the scope and integrate electricity, thus following the general trend around smart grids, but in general, eco-districts in France are more concerned with heat demand and do not follow the innovative or systemic approach observed elsewhere in Europe.

- How does the energy diversification within the same building or neighborhood and among different urban scales require innovations in institutional operations and in project governance?

We raised the question whether energy diversification and efficiency efforts required innovations in institutional operations and functions as well as in project governance modes. The main finding is that innovations in project management and overall governance were even more important than technological innovations. Having to associate different types of energies on the same building or part of an eco-district led actors to innovate in their everyday operations, competences, skills and coordination. Our empirical findings offer empirical evidence for Pierson's path dependency and Young's institutional fit.

A few examples will suffice to highlight our argument. In terms of work procedures, architects explain that they had to learn to work synchronously with different actors that were traditionally involved only at later phases of the conception and construction process. Other actors had to modify their professional networks, not being able to find the required skills for their projects. Others eventually found it worthwhile to internalize new skills or even create a new job, a transversal project coordinator, to ensure that the different teams would work in a coordinated manner to improve the project's overall energy quality.

In De Bonne, the actors observed that the project's greatest benefit was experimenting with new ways of "doing their jobs", not new technologies. This is not entirely surprising since the project was not highly innovative in terms of technologies – besides captors for the continued evaluation of the building's performance.

In the case of IssyGrid®, however, the project is high tech intensive with a highly innovative smart grid. But even in this case, the private actors involved insisted that innovations in project governance were more important in their energy experimentations than technical innovations, even though the latter are highly important. Their main goal is integrating different energy types, uses and sectors to reach higher energy efficiency and learn how to proceed in this type of collaborative project. Each actor is associated to a specific component of the project, but these components need to be integrated into a coherent whole: public lighting with electric cars used as storage, tertiary buildings with residential units, photovoltaic systems with small wind turbines…

The actors insist on the fact that while each member of the private consortium can engage in its own specialized energy sector, individually none is able to manage the whole project. Some of the actors may even be in competition with another, but in this project, coordination is required, otherwise global objectives cannot be reached. So, new rules relative to the sharing (or not) of new information and results from the project had to be devised and new conflict resolution modes developed, in order for the global project to work. For all interviewees, this allowed to develop a new business model and new professional interactions between private actors. This new model is for them the most important benefit of the experiment.

To get back to our theoretical framework: while none of the actors interviewed had to modify their identity (Young, 2002) – perhaps, the required changes were not deep enough to warrant this – all actors changed some of their operating modes and governance culture. And while none of them engaged in a formalized analysis of the obstacles to achieving their objectives, they all had an empirically clear understanding of what needed to be done relative to what used to be (Pierson, 2000); the changes they engaged in all aimed at removing obstacles to achieving their desired objective.

- How do organizations transform their business models to manage the energy storage and diversification at the different urban scales?

The content analysis of the interview responses revealed that actors experienced four types of transformations of business models: 'Business-as-usual', Adjustment, Opportunistic and Business model Redesign types. Business models comprise four elements: value proposition, supply chain, customer interface and financial model.

'***Business-as-usual'*** implies that the actors involved remained with their habitual business models. Energy efficiency was not at the heart of their value proposition. A promoter of an eco-district explained for example that his clients valued the proximity of the district to the city center (*"the land had value"*) more highly than its energy performance. The solution they sell was a conventional one. Regarding the supply-chain, the actors did not change their business partners. They used existing skills, or acquired skills through trial and error. The financial models also remained unchanged, with a similar distribution of value amongst actors in the chain, and costs and revenues close to existing practices.

Adjusted business models differed only marginally from those adopted in other projects. The actors who adopted them reacted to a shift in (public) demand. They did not fundamentally change their partners, value networks, customer interfaces or financial model. They followed an incremental logic by adapting their value proposition to new (governmental) demand. The combination of two different value propositions – social housing and energy efficiency – is an example that could gradually be systematized under certain institutional pressures. The value proposition was also enhanced with intangible value: social benefits (social diversity), environmental benefits (energy efficiency), reputation and electoral advantages. It seems that the financial model also extended beyond the conventional economic approach: the actors involved earned not just money but also a reputation as an expert for eco-districts. The profit model was also affected by European subsidies, reducing investment costs.

Opportunistic business models were modified to capture the opportunity linked to growing demand for energy efficiency, but without disrupting the existing business model structures. The actors took into account new trends in the building market (new ways of assessing buildings and energy costs, new types of ownership, new technological solutions), and saw themselves as part of the evolving ecosystem of sustainable urban districts. To this end, these actors invested heavily in acquiring new skills, and were able to question and reorganize their networks of partners to create the value that they aimed to generate. The focus was in particular on more collaboration along the value chain. In some cases, the customer interface was transformed. The change in the value proposition was radical, e.g. *"We were builders, not energy solutions providers*".

The Redesign of the business model contains the most innovative business models. All components of these business models differ from those in the industry's dominant business models. Some companies shifted towards offering services rather than products. This makes sense, given the rise of maintenance issues related to energy efficiency solutions. Customers are now more likely to buy (or rent) buildings or properties with maintenance or energy performance contracts – thus the customer interface changes. Some actors adopted a proactive strategy by creating a common platform for discussing the partners' expertise and complementary markets. The idea was to become a prescriber rather than a supplier for communities. The partners involved were either long-term associates, or new partners able to explore different innovation avenues. The terms *"open innovation"* and *"logical laboratory"* were mentioned by these actors, who considered that they were building *"the energy building block of the smart city"*, with multi-level energy optimization, "big data" analysis, etc. The value created by these new models required that the actors acquired new skills, by forming teams or hiring outside expertise. Such transformations often disrupted also partner networks, bringing in new groups of actors.

- How can an innovative scale of energy design and management reveal an existing reference framework combining public regulation and (private) expertise?

In France, heat is traditionally generated from fossil fuels or electricity at the scale of the housing unit or building[6]. So, heat production at the scale of building blocks or districts is a recent innovation: it was encouraged by the approach of eco-districts.

It presents some economic advantages over individual or building heating but needs a higher investment for the pipe network. Its competitiveness depends on the connection of the closest buildings around a common heat unit. So, most of the district or block heat units in France are built in new developments and where

[6] Only very few French cities have an urban heating network.

municipalities manage the land: land purchase agreements include the connection to the district-heating network. Actually, no law or regulation can impose the energy used for heating to owners (or developers and housing companies).

The analysis of these block/district heat projects reveals also other major elements that limit their development in France. First, the *Maîtrise d'ouvrage publique* (public contracting party) Act makes a strong distinction between three types of actors:

- *maître d'ouvrage* (buyer ordering a construction project, e.g. a community, a real estate promoter, a social housing agency…)
- *maître d'oeuvre* (designer and manager of the construction process, e.g. an architect, a design firm…)
- construction firm

The law considers the *maître d'ouvrage* not competent as a constructor or manager of the construction process. The *maître d'oeuvre* carries the main risk of the construction process, and insurances offer very different rates to the three types of actors. So even if the *maître d'ouvrage* has usually the most expertise in terms of building or (energy) network management, he is reluctant to suggest solutions during design stages because he does not want to engage his responsibility in case of future problems. That leads to a sequential and non-collaborative process of design for public projects and, by extension, also for private projects. Second, the national electricity regulation requires the injection of all renewable electricity into the power grid that is usually managed by the national company. Consequently, renewable electricity sources are not substantially integrated in the design of the energy systems at building or district level. Third, resulting from the traditional organization of the building and energy sectors and their specific regulations, the compartmentalization of expertise is a major disincentive for energy projects at district level. E.g., many energy consultants are able to design the energy systems of a building or group of buildings belonging to the same organization, but they are struggling with defining both technical and legal relationships between energy users and different developers. And architects ignore the types of agreements between occupants and energy distributors.

Combined heat and power inside a residential building concentrates the problem of compartmentalization of expertise. Electricians and thermal engineers do not use the same vocabulary and concepts. The juxtaposition of different safety rules (fire, fuel combustion, electricity...) usually mastered by different actors (architect, heating and electricity consultants, contruction firm) requires numerous adjustments and additional studies.

Even if the technologies are not new, implementing an energy sytem at district or block level in coordination with several organizations is an innovation. Innovative socio-energy nodes should be considered as boundary objects (Star & Griesemer, 1989), revealing the specific knowledge infrastructures of the different building and energy actors. As such, these knowledge infrastructures are elements of the current reference framework (Flichy, 1995).

III. Conclusion & limits

a. What did we learn on the future of energy storage?

1. Local authorities strongly influence the emergence of block and district energy system.

2. Building actors and energy grid actors are not central motors for the deployment of energy systems at district or block level, except in the experimentation with information and energy flows (IssyGrid®).
3. Intermittency does not appear to be a main issue at district or block level, but smart grid systems do. Intermittent renewable thermal energy is often stored for consumption of several hours or days at building level, by coupling with a (building-scaled) boiler or a heat network. Intermittent electricity from renewable sources is always sold to the electricity distributor and therefore managed outside of the eco-district (and of course the building) via transitory processing (mechanical or chemical).
4. District energy systems mainly produce heat from renewable sources (solar, biomass, heat pump), or cogenerate heat and power. Solar and wind powers are connected to the electric grid independently of the district governance.
5. The combination of energy systems within cities is rather due to an assembly of socio-energy nodes than to a systematic approach to energy management.
6. Eco-districts are for companies a source of learning and reputation, even if they were initially obliged by communities to participate.
7. Some companies seize the opportunity to develop radically different business models: these models could become dominant if their solutions are adopted by the market.
8. Before 2040, new business models in the energy sector could become a standard under a new framework bringing together aspects of energy, building and urban planning.

b. Did the interdisciplinary research lead to new insight for disciplinary research?

1. Disagreements about categorization are a frequent pitfall of interdisciplinary projects. Choosing common ground helped identify these disagreements.
2. The flexibility and hybridity (social and technical) concept of SEN (socio-energy nodes) allowed the appropriation by each discipline and the exchange between disciplines
3. The energy transition presumes changes in different fields: regulation, market, planning... Studying it required interdisciplinarity.

c. Limits

1. Our study deals with a French case, characterized by weak power of local authorities, relative centralization of the electricity sector, late policies on renewable energy compared to North European countries, and limited concern about intermittency.
2. The weak number of cases should be completed by extensive surveys.

d. Further perspectives of research

We will design long term scenarios of energy coordination to highlight the effects of regulation in the building, energy and planning sectors. In addition, we suggest using assemblages of SEN (or a similar concept) as a means to describe energy flows and energy management in built environments. The energy flows and management will allow us to understand the conditions of technology implementation and multi-energy smart grid development.

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